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Density and biomass of *Campsurus* sp. (Ephemeroptera) and other macroinvertebrates in an Amazonian lake impacted by bauxite tailings (Lago Batata, Pará, Brazil)

by

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Abstract

For 10 years (1979 to 1989) the Lake Batata received about 18 million cubic meters per year of effluent from the washing of bauxite. About 30 % of its area was impacted. The main goal of this study has been the to evaluation of the effects of the bauxite tailing dumping on the density and biomass of the benthic macroinvertebrates community and, especially, on the population of *Campsurus* sp. Three sampling sites has been determined in each of the three lake regions (impacted, transition and natural); periodicity of samples has been chosen throughout the four periods of the flood pulse (high water, drawdown, low water and flood) between June 1996 and March 1997. The limnological variables measured were temperature, depth, dissolved oxygen and transparency (of water column), available phosphorus, total nitrogen and organic matter (in the sediment). Variables were organized by Pincipal Components Analysis (PCA). Density results for community of benthic macroinvertebrates were significantly lower (Kruskal-Wallis, $p < 0,05$) in the impacted region; the highest values were found in the natural and transition regions. Ostracoda, Chaoboridae, Oligochaeta and Chironomidae were the predominant taxonomic groups in the natural and transition regions; in the impacted region *Campsurus* sp. was the group with the highest relative importance with regard to density and biomass.

Keywords: **Amazonian lake, clear water, bauxite tailing, benthic macroinvertebrates, *Campsurus* sp.**

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Introduction

Communities of benthic macroinvertebrates consist of an assemblage of organisms adapted to ecological conditions imposed by the aquatic environment (MERRITT & CUMMINS 1984). Physical and chemical factors, such as the type of substrate, oxygen availability, pH, temperature and the physionomy of the environment (lotic or lentic), are considered to be key factors determining the structure and dynamics of benthic communities (PRAT 1991). These communities also transform the environment and perform diverse ecological roles in continental aquatic environments.

Studies developed by THIENEMANN (1920, 1954), comparing species of chironomids of German lakes in different stages of eutrophication, served as a basis for more recent studies of the possible use of macroinvertebrate communities in biomonitoring tasks (LOEB & SPACIE 1994; RESH & ROSENBERG 1989; ROSENBERG 1992; SCHINDLER 1987). In these research, the structure of the communities and the biology of the species found resulted in the creation of many biological indexes of water quality, with the use of species as bioindicators (ENGLE et al. 1994; LOEB & SPACIE 1994).

Among the diverse phyla that compose the macroinvertebrate benthic community, the arthropods are the most abundant group, the class Insecta being represented by nine orders, which include aquatic families comprising the most representative section of lakes and rivers fauna (PÉREZ 1992).

The order Ephemeroptera stands out as an important component of the continental aquatic ecosystems. It is found in different kinds of environments. Some Ephemeroptera species are generalists, found in many environments; while others are specific to a certain habitat (MERRITT & CUMMINS 1984; DA SILVA 1994). This group is often used in many biomonitoring works, due to the great diversity of habitats, and especially, because of sensitivity of some species to alterations of the abiotic variables in the freshwater ecosystems.

The genus *Campsurus* Eaton 1868 (Ephemeroptera: Polymitarcyidae) is frequently found in the amazonian lacustrine environments. It has an important ecological role as a food item in the diet of many species of fishes and in the process of bioturbation (FITTKAU et al. 1975; NOLTE 1987, 1988).

The amazonian aquatic ecosystems, such as the great rivers and lakes, are subjected to great fluctuations of water level. They are influenced by the marked variation in the pluviometric precipitation between the rainy and the dry season (JUNK 1984). This marked fluctuation of the fluviometric level results in the determination of two periods with distinct characteristics in amazonian aquatic environments, with a high and a low water periods.

Fluctuation in the water level of the amazonian aquatic ecosystems has a great influence over the metabolism and production of these ecosystems (FISHER & PARSLEY 1979; JUNK et al. 1989; SIOLI 1984), as well as over the diverse aquatic communities, such as aquatic macrophytes (JUNK & HOWARD-WILLIMS 1984), zooplanktonic and phytoplanktonic communities (BOZELLI 1994; HUSZAR 1996; ROBERTSON & HARDY 1984; UHERKOVICH 1984), fish communities (GÉRY 1984) and benthic macroinvertebrate communities (IRMLER 1975; REISS 1977).

Many limnological researches developed in the Amazon are focused on natural environments. Few works are devoted to the study of the effect of anthropic activities on the amazonian aquatic ecosystems (BOZELLI 1991). Among those related to anthropogenic influences, many deal with the effect of the hydroelectrical reservoirs JANUÁRIO & FISH 1992; JUNK et al. 1981; JUNK & MELLO 1987) or the dumping of domestic effluents into small bodies of water (Igarapés) close to the city of Manaus (CLETO FILHO 1998).

Studies focusing on the community of benthic macroinvertebrates in the amazonian region are quite rare (CLETO FILHO 1998). Studies of this community in lake Batata as a bioindicator of the effect of the release of bauxite tailings have been carried out since 1991 (CALLISTO & ESTEVES 1995, 1996; FONSECA et al. 1998). This community has shown itself as one of the best indicators of the effect of the release of bauxite tailing, especially with regard to its structure.

The goal of this research was to study the effect of bauxite tailing release on the community of benthic macroinvertebrates, and to show alterations in the values of density and biomass of the community's main groups.

Study area

Lake Batata (Fig. 1) is located between 1°25'S and 1°35'S and 56°15'W and 56°25'W, in Porto Trombetas, Municipality of Oriximiná, state of Pará, Brazil. Situated at the right margin of the Trombetas River, a left tributary of the Amazon River, lake Batata is a typical floodplain lake, with a total surface varying between 18 and 30 km^2, with great fluctuation of the water level (PANOSSO et al. 1995). It has four distinct phases of its inundation pulse (high waters, drawdown, low waters and flood). Great variations of the water level in the lake Batata are provoked by the Trombetas River, a typical clear water river (SIOLI 1950), to which it is periodically linked.

For ten years (1979 to 1989), around 50.000 $m^3 \cdot day^{-1}$ of an efluent formed by tailings of bauxite processing was dumped into lake Batata. Landfilling of approximatily 30 % of its total area was the result (SILVA 1991). Tailings are formed in the processing of the bauxite. The ore in a crude state is separated from the impurities (clay), through decantation (ESTEVES et al. 1990). The tailings are rich in solid particles of very fine clay, with high concentrations of iron, aluminum and silicate oxides (LAPA & CARDOSO 1988).

Material and methods

Three sampling sites were established. The first site consists of the impacted area with bauxite tailing, or rather, a thick layer of effluent over the natural sediment. The second site represents the transition zone between the impacted and natural areas. In this site bauxite tailing may be observed in 5 to 10 cm lauyers, often mixed with natural sediment. The third site, the natural area, has no vestiges of the bauxite tailing over the sediment. In each of these sites three sampling stations were established (Fig. 1), all within the limnetic region, inundated throughout the year, even in the low water season.

Water temperature was measured with an electronic thermometer, model Fac 400, with 0,1 °C precision. Transparency of water column was infered through the visibility of a Secchi disc of 25 cm of diameter. Oxygen concentrations were determined by Winkler titration, modified by GOLTERMAN et al. (1978).

The sediment samples were collected with a modified corer proposed by AMBÜHL & BÜHRER (1975), with 8 cm of diameter, presenting a sampling surface of 50 cm^2. For the study of benthic macroin-

vertebrates 10 samples were collected from each station, the first 10 cm of the sediment were analyzed, sice this layer has been considered by many authors as the most significant fraction of this community (CECHERELLI & FABBRI 1978; ROSENBERG & RESH 1993). Samples with live organisms were washed 0,5 and 1,0 mm mesh sieves and then separated with a Zeiss stereoscopic microscope.

For estimates of biomass, organisms were separated according to their taxonomic groups, and placed on aluminum boats, previously weighed. The material was dried in a stove at 60 °C for 48 hours. After drying, material was weighed in a Mettler (UMT2) balance, with 0,1 μg precision. Biomass was estimated by gravimetry and results expressed in miligrams of dry weight (mg D.W.).

With regard to abiotic variables of sediment, the concentrations of total organic nitrogen by the Kjeldahl method (BEZERRA 1987); available phosphorus (MORENO 1987) and the percentage of organic matter (% OM) after ignition at 550 °C, for 4 hours were analyzed (JACKSON 1962).

Results

Principal Component Analysis of limnological variables

Results obtained by the Principal Component Analysis are shown in Figure 2, where the abiotic variables and sampling stations are plotted. In spatial representation, the first two axis were used, comprising 72.49 % of the explanation of the total data variation.

The abiotic variables formed three distrinct groupings, the sediment variables (total-N, available-P and organic matter) compose the group plotted in the first quadrant, transparency (Secchi) and depth are plotted in the second quadrant, and in the fourth quadrant temperature (surface and bottom) and surface oxygen are plotted.

For the spatial distribution of the sampling stations with regard to abiotic variables, two general trends may be observed. The first concerns the distribution related to fluctuation of the flood pulse where the stations (impacted, transition and natural) have the same pattern of dispersion. Samples in the low water period are grouped with temperatures of the water column in both depths and with dissolved oxygen, since the highest values of these variables were observed in the sampled stations in this period. In the high water period, the stations were positively grouped with Secchi and depth, due to the high values of these variables in this period.

The second grouping of the stations regarding the variables concerns sediment variables (total nitrogen, available phosphorus and organic matter). When these variables are taken into consideration, a discontinuity of the sampling stations may be observed. They are divided into two distinct groupings. The first one is related to the natural and transition regions, since it is positively associated with these variables and reflects the highest concentrations in these regions. The second grouping comprises the stations impacted with bauxite tailings, being mostly plotted in the opposite quadrant of the sediment variables, and reflect the lowest concentration of these elements in the impacted region.

Density and biomass of benthic macroinvertebrate community

The results of average density (ind · m^{-2}) and biomass (mg · m^{-2}) for each sampling region during the studied period are presented in Figure 3. It may be observed that the higher values of density of the benthic macroinvertebrate community were found in the natural and transition regions. The lower values were observed in the region impacted by bauxite tailings. As for biomass values, they were usually higher in the impacted area, when compared to values in other regions.

In the natural region of lake Batata average values of density varying between 993(± 164.3) ind · m^{-2} in the flood and 1,233(± 525.7) ind · m^{-2} in the low water period were registered. In the transition region average values of density fluctuating between 913(± 271.4) ind · m^{-2} in the flood and 2,047(± 484.8) ind · m^{-2} in the drawdown period were found. The region impacted by bauxite tailings exhibited the smallest values of density of benthic macroinvertebrates throughout the sampling period, average densities oscillating between 440(± 190.0) ind · m^{-2} in the drawdown period.

The average values of biomass found in the natural region fluctuated between 100.30(± 18.50) mg · m^{-2} in the high water period and 324.2(± 52.20) mg^{-2} in the low water period. The pattern observed in the transition region for the variation of biomass was the same found in the natural region. In the impacted region lowest values were observed in the drawdown period, with 86.34(± 23.30) mg · m^{-2}, highest value was 1,093.68(± 687.15) mg · m^{-2} in the low water period.

The densities of benthic macroinvertebrates in the natural and transition regions are significantly different (Kruskal-Wallis, $p < 0.005$) from those of regions impacted by bauxite tailings. As for biomass values, significant differences (Kruskal-Wallis, $p < 0.005$) were found between the natural and impacted regions; the transition zone did not exhibit any significant difference (Kruskal-Wallis, $p > 0.005$) when compared to the other regions.

Results of the relative percentage of main groups (density) in the different sampling regions are shown in Figure 4. In the natural and transition regions, Oligochaeta, Ostracoda, Chironomidae and Chaoboridae were the dominant groups throughout the sampling period. In the region impacted by bauxite tailings nymphs of *Campsurus* sp. were dominant, with a percentage higher than 66 % of the total density of organisms, practically throughout the sampling period. Exception is due to the drawdown period, when no nymphs of this genus were found in the sediment of the impacted region.

As for the relative contribution of biomass (Fig. 5), in the natural and transition regions, Ostracoda, Oligochaeta, Chironomidae and Chaoboridae were the groups with greatest relative importance. In both regions, in the low water and flood periods, nymphs of *Campsurus* sp. were observed, with a percentage between 14 and 28 % of total biomass in these periods. In the impacted region, *Campsurus* sp. exhibited values above 93 % of the total biomass found in the different sampling periods Exception is due to the drawdown period when no nymphs of this genus were found.

Using the data of relative percentage of density and biomass of the community of benthic macroinvertebrates in the cluster analysis (Fig. 6) enabled the authors to identify two distinct communities in lake Batata.

Figure 6a represents the cluster analysis concerning the relative density this made possible the identification of 3 distinct groups of stations. The first group represents the natural and transition regions in the high water and flood periods. The second is formed by the natural and transition regions in low water and by the impacted region in the flood. The third group consists of the impacted area in samplings made during high water, drawdown, and low water periods. Sampling of the transition region in the drawdown period was plotted disjointedly from that of other regions, due to high densities in this region and during this period. Relative dominance of Chaoboridae /70 %) represented the highest value of density throughout the sampling period and in all sampled regions.

Low density values and dominance of *Campsurus* sp. in the impacted region resulted

in it being separated from other regions of the lake Batata. It presented a distinct taxonomic composition from that of other regions in all sampling periods, with the exception of the drawdown period, when no nymphs of *Campsurus* sp. were found.

The cluster analysis concerning relative contributions of taxonomic groups related to their biomass (Fig. 6b), exhibited a similar pattern to the one found in the density analysis. Three distinct groups were established, composed by the regions studied. The first group is related to the natural and transition regions in the high water and drawdown periods, including the impacted region during the latter. The second group comprises the natural and transition regions in the low water and flood periods. The third group consists of the impacted region in the high water, low water and flood periods. Results reflect the uniqueness of the impacted region when it is compared to other regions of the lake Batata. Biomass, is directly related to the dominance of *Campsurus* sp., and is shown by high values of biomass in this region and by low values of biomass of the other taxonomic groups.

Discussion

The effects of anthropogenic activities on the aquatic ecosystems, including in the disturbance of limnological variables and, of the communities of benthic macroinvertebrates, were studied by many authors, such as BREZONIK et al. (1990); CORKUN (1996); HÄMÄLÄINEN & HUTTUNEN (1996); MATTHAEI et al. (1997); PLÉNET et al. (1996); WALLACE (1990).

Among the limnological variables that best explain the effects of anthropic impacts over this community, the physical and chemical characteristics of the sediment limit the composition, distribution and dynamics of the benthic communities (ARUNACHALAM et al. 1991; BICHI & ZETTLER 1994; MACLASAAC & ROCHA 1995; QUINN et al. 1992; SANDERS 1968). According to these authors, anthropogenic influences resulting in the disturbance of physical and chemical characteristics, such as the reduction of nutrient concentrations and modification of the granulometric fractions can be held responsible for the decrease of diversity, density and biomass. These alterations are responsible for the disappearance of some species of the benthic community, especially in environments where the nature of the sediment is completely disturbed (CALLISTO et al. 1998).

The variable densities found in this research in different regions of lake Batata corroborate the results obtained by CALLISTO (1995, 1996) and FONSECA et al. (1998). The highest densities of benthic macroinvertebrates have been observed in the natural region of the lake Batata, whereas in the impacted region the lowest densities were found throughout the whole period.

In a research performed by CALLISTO (1996) during 1992 to 1994, Chironomidae, Chaoboridae and Oligochaeta were the dominant groups in all regions of the lake Batata, including the impacted region. These results diverge from those recorded in the present research, where Oligochaeta, Chironomidae, Ostracoda and Chaoboridae were the dominant groups in the transition and natural regions, while nymphs of *Campsurus* sp. were dominant in the impacted region. These results confirm the importance of long term biomonitoreded studies, as a tool to a better comprehension of the community's structure alteractions.

Among the limnological variables used for the characterization of the sampling regions, the variables related to the water column, such as temperature, depth, dissolved oxygen and transparency, offered only a small contribution to the disjunction of the sampling stations. Therefore, it may be said that these variables were not limiting in the determination of the communities of benthic macroinvertebrates in the different regions under analysis. This fact corroborates results found by BOZELLI (1991), for whom these same variables were held as not important for the characterization of the effect of bauxite tailings with regard to the zooplanktonic community.

On the other hand, variables related to the sediment, such as: total nitrogen, available phosphorus and organic matter, have shown themselves to be of importance for the disjunction of the sampling stations and, consequently, to distinguish the communities of benthic macroinvertebrates. The regions where the highest concentrations of nutrients were detected (natural and transition) were the stations in which densities and taxonomic richness were highest. In the impacted region, where low concentrations of these nutrients were found, the lowest densities as well as the almost exclusive dominance of *Campsurus* sp. were observed.

Studies related to the communities of benthic macroinvertebrates in the Amazon have shown that this community is strongly influenced by concentrations of nitrogen, phosphorus and organic matter in the sediment. The highest densities and taxonomic richness are found in the areas where these nutrients have higher concentrations (CALLISTO & ESTEVES 1996; JUNK & FURCH 1984; REISS 1977).

The values of total biomass of benthic macroinvertebrates community obtained for lake Batata differ among the sampling regions, with yearly averages of 0.21 $g \cdot m^{-2}$ and 0.25 $g \cdot m^{-2}$, respectively for the natural and the transition regions, and 0.63 $g \cdot m^{-2}$ in the impacted region. Studies regarding the biomass of this community in Amazonian aquatic environments, have exhibited discrepant values found by IRMLER (1975) in lake Januari (2.40 $g \cdot m^{-2}$), with white waters, and in the river Tarumã Mirím (0.27 $g \cdot m^{-2}$), with black waters may be cited. FITTKAU et al. (1975), studying ecosystems of white and black waters, established values of biomass of benthic macroinvertebrates communities varying between 2.06 and 6.20 $g \cdot m^{-2}$ for white water environments and between 0.44 and 1.15 $g \cdot m^{-2}$ for black water environments. Studying black water environments REISS (1977) and NESSIMIAN (1985), recorded values of 0.03 $g \cdot m^{-2}$ (lake Tupé) and 0.22 $g \cdot m^{-2}$ (lake Redondo).

Comparing the values presented by many aquatic environments with the values of benthic macroinvertebrates biomass found in this research, we may conclude that these are similar to values found in black water environments, despite the fact that the lake Batata is a clear water environment, acknowledged as being less productive than white water environments. These results corroborate the pattern found by SCHMIDT (1973) and SIOLI (1984) of the productivity of many amazonian aquatic environments, on rather the clear and black water environments being less productive than the white water ones. However, the scarsity of such researches in clear water environments prevents the comparison of the results of the present research with other environments with similar ecological characteristics.

The nymphs of *Campsurus* sp. were dominant in the impacted region through most of the period, with the exception of the drawdown period during which no nymphs of this group were found. On the other hand, in this period an increase in the density and biomass of other taxonomic groups was detected in this region. This fact may be related

to the decrease of competition between the nymphs of *Campsurus* sp. and those of other groups, since the nymphs are adapted to the colonization of environments with characteristics similar to those found in the impacted region. Therefore, with the disappearance of the nymphs of *Campsurus* sp. from the sediment of the impacted region, the colonization of this region by the other taxonomic groups has been detected.

Results obtained in both grouping analyses reflect a difference between the community present in the impacted region and that of other regions. Therefore, in lake Batata, the dominance of the nymphs of *Campsurus* sp. in the region impacted by bauxite tailings (contributing with more than 93 % of biomass values found in these areas), as well as the high densities of the genus, restricted to this region, show how well this group is adapted to the ecological conditions imposed by the presence of the bauxite tailings.

From the results obtained in this research we may conclude that the limnological abiotic variables measured in this work form two distinct groups. The first one regards the variables of the water column, determining the explanation of the temporal variation, i.e. related to the flood pulse. The second group is represented by variables of the sediment, determining the spatial variation and distinguishing the stations studied in lake Batata with regard to the presence of bauxite tailings.

The presence of bauxite tailings resulted in the deposition of thick layers of clay over the original sediment. A sediment of an extremely fine granulometry has been established. It is poor in nutrients such as nitrogen, available phosphorus and organic matter. It has also a negative effect over the community of benthic macroinvertebrates, since it causes the decrease of values of density and of taxonomic groups dominant in the impacted regions.

In the impacted regions nymphs of *Campsurus* sp. were dominant throughout the flood pulse. This fact shows how well this group is adapted to the ecological conditions imposed by bauxite tailings.

Resumo

O lago Batata recebeu durante 10 anos (1979 a 1989) cerca de 18 milhões de m^3 por ano de um efluente proveniente da lavagem de bauxita, que impactou cerca de 30 % de sua área. Com o objetivo de estudar o efeito do lançamento do rejeito de bauxita sobre a densidade e biomassa da comunidade de macroinvertebrados bentônicos e principalmente sobre a população de *Campsurus* sp. Foram estabelecidas 3 estações amostrais em cada uma das regiões (impactada, transição e natural), com periodicidade amostral ao longo dos quatro periodos do pulso de inundação (águas altas, vazante, águas baixas e enchente) entre junho de 1996 e março de 1997. Foram mensuradas temperatura, profundidade, oxigênio dissolvido e transparência da coluna d'água e, no sedimento, fósforo disponivel, nitrogênio total e matéria orgânica, sendo estas ordenadas em uma Análise de Componentes Principais (PCA). Os resultados de densidade obtidos para a comunidade de macroinvertebrados bentônicos revelou valores significativamente inferiores (Kruskal-Wallis, $p < 0,05$) na região impactada, sendo as maiores densidades observadas nas regiões natural e transição. Ostracoda, Chaoboridae, Oligochaeta e Chironomidae foram os grupos taxonômicos predominantes nas regiões natural e de transição enquanto que para a região impactada *Campsurus* sp. foi o grupo de maior importância relativa em termos de densidade e principalmente de biomassa.

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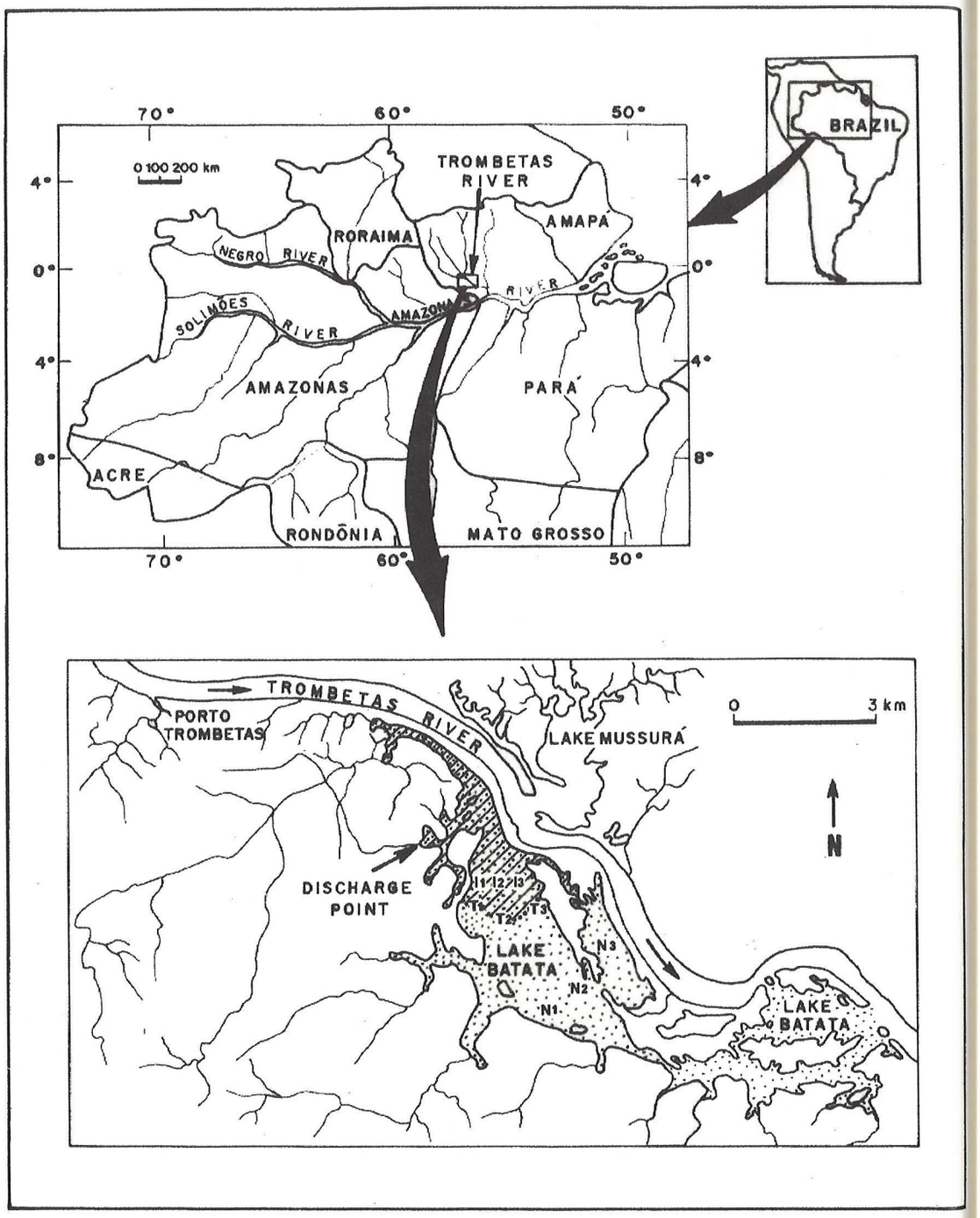


Fig. 1:
Map of the lake Batata and the respective sampling stations: I1, I2, I3 (impacted region), Ti, T2, T3 (transition region) and N1, N2, N3 (natural region).

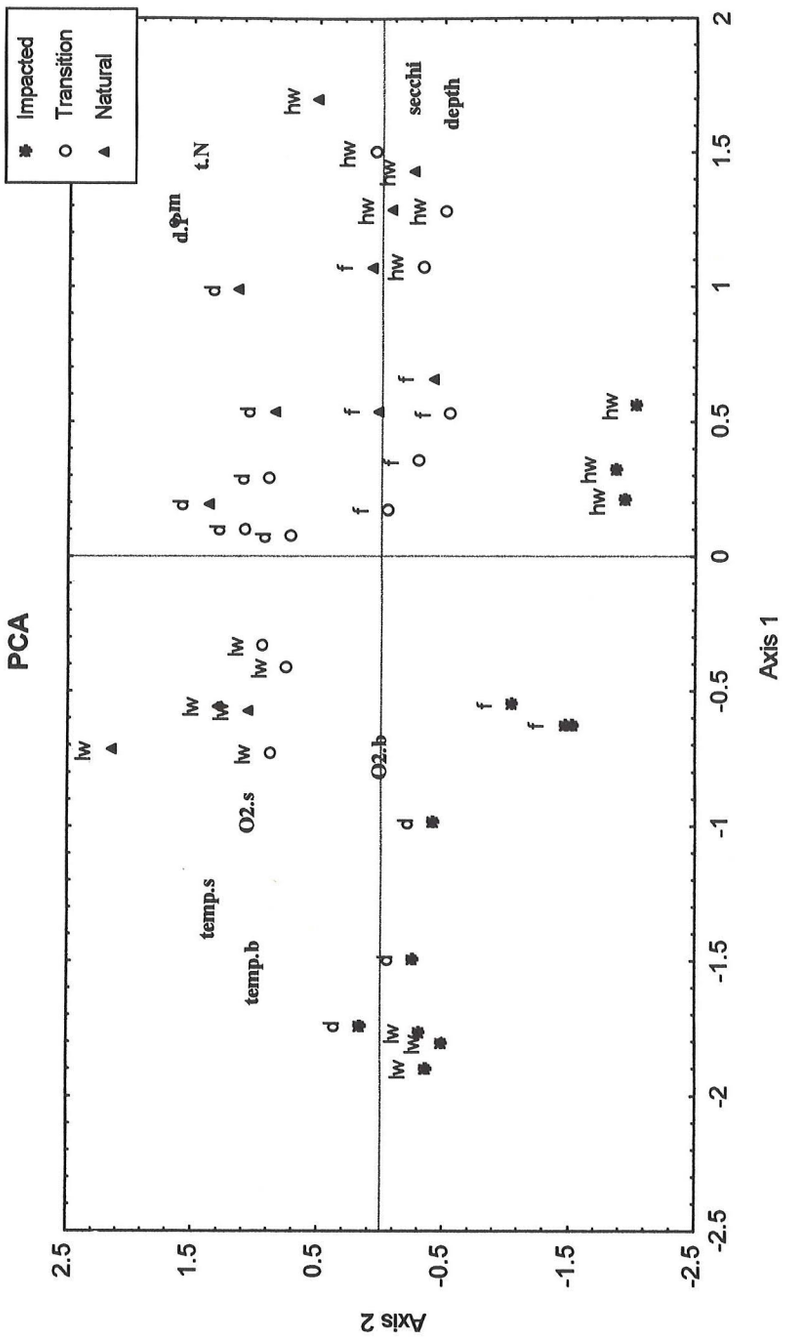


Fig. 2:
Principal Component Analysis ordinating the abiotic variables temperature of surface and bottom (temp.s and temp.b), dissolved oxigen of surface and bottom (O2.s and O2.b), secchi, depth and available-P (d.P), total N (t.N) and organic matter (o.m), on the differents stations in the natural, transition and impacted regions in high water (hw), drawdown (d), low water (lw) and flood (f) at the lake Batata between June 1996 and March 1997.

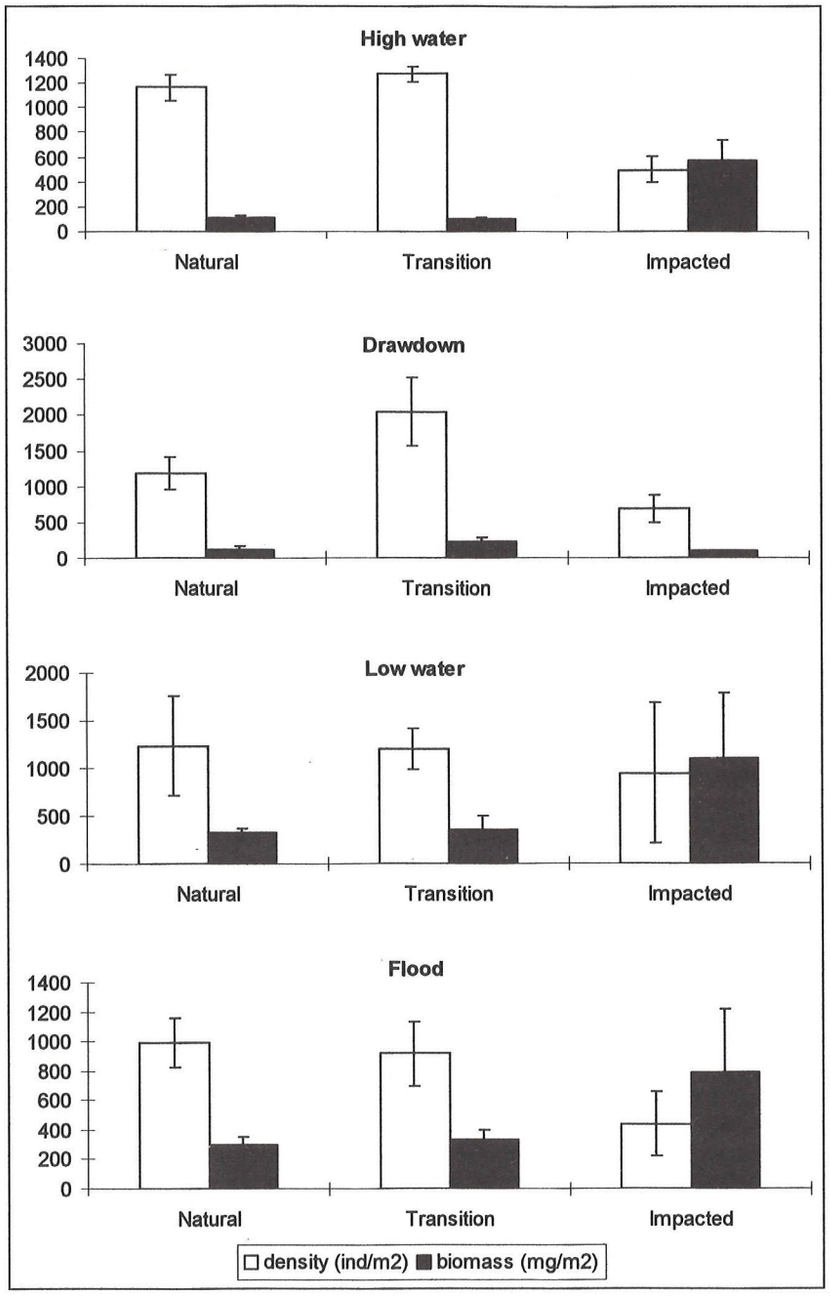


Fig. 3:
Average values of density and biomass of the community of benthic macroinvertebrates in the natural, transition and impacted regions of the lake Batata through the four sampling periods.

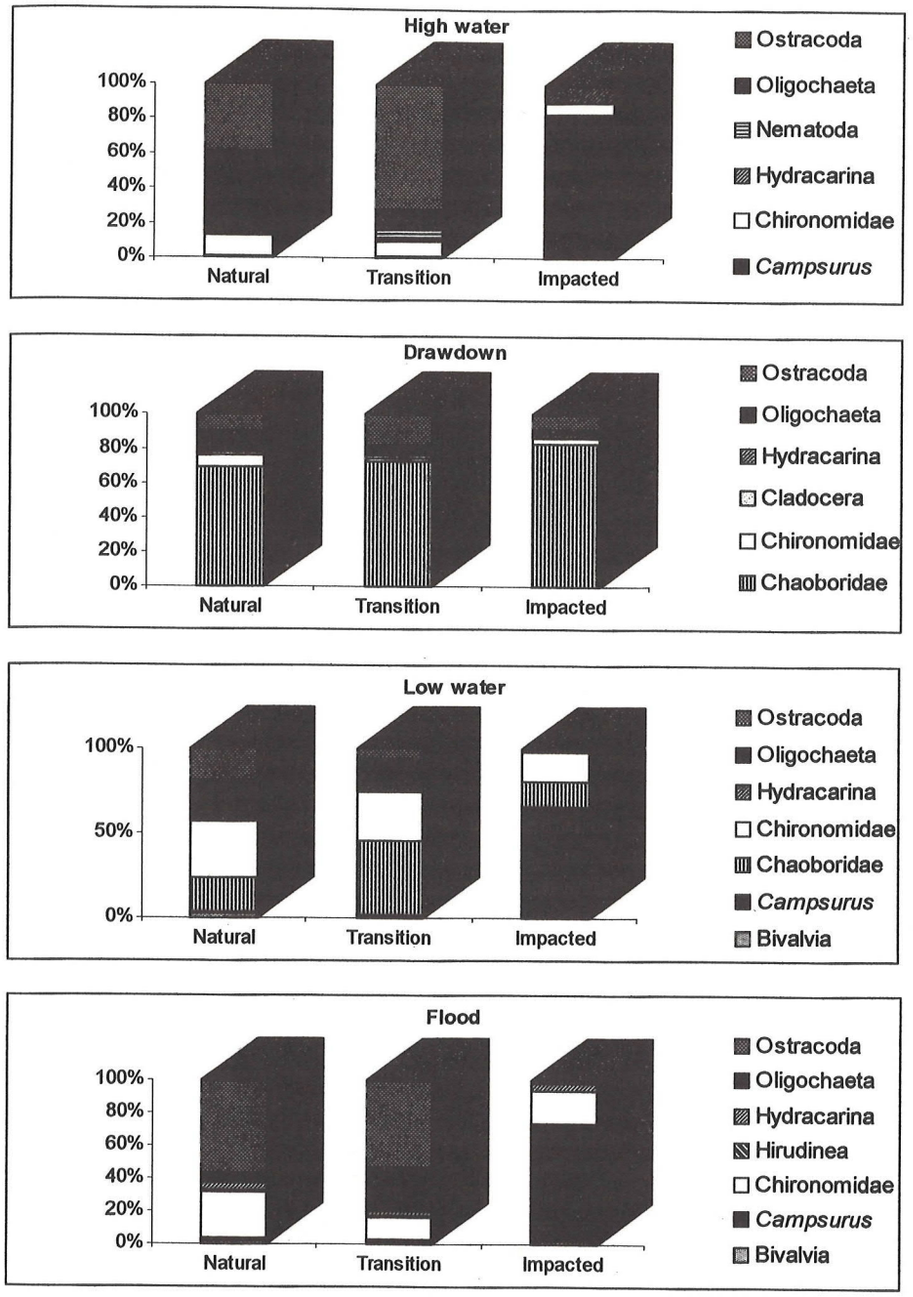


Fig. 4:
Relative contribution of the main taxonomic groups of the community of benthic macroinvertebrates regarding average densities in the natural, transition and impacted regions of the lake Batata.

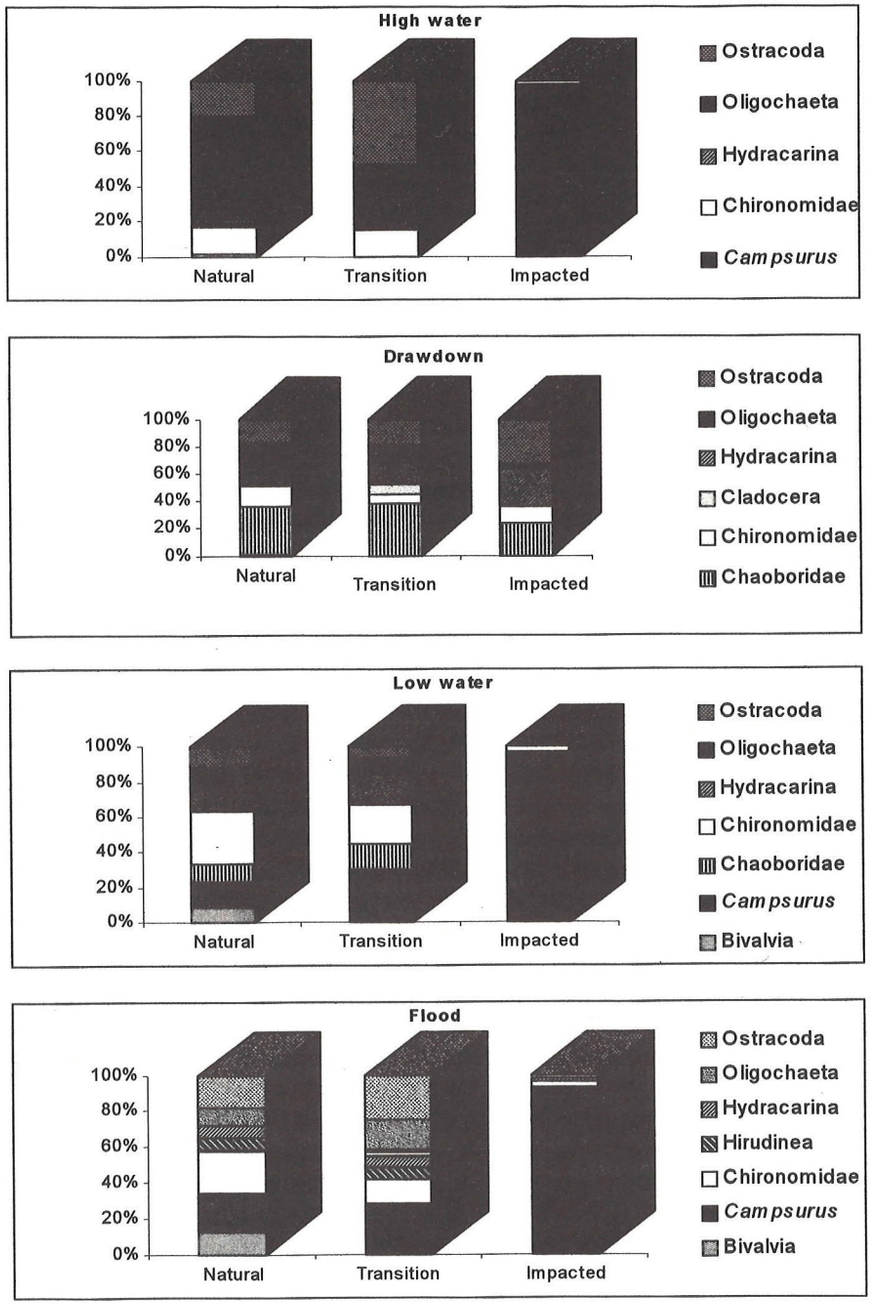
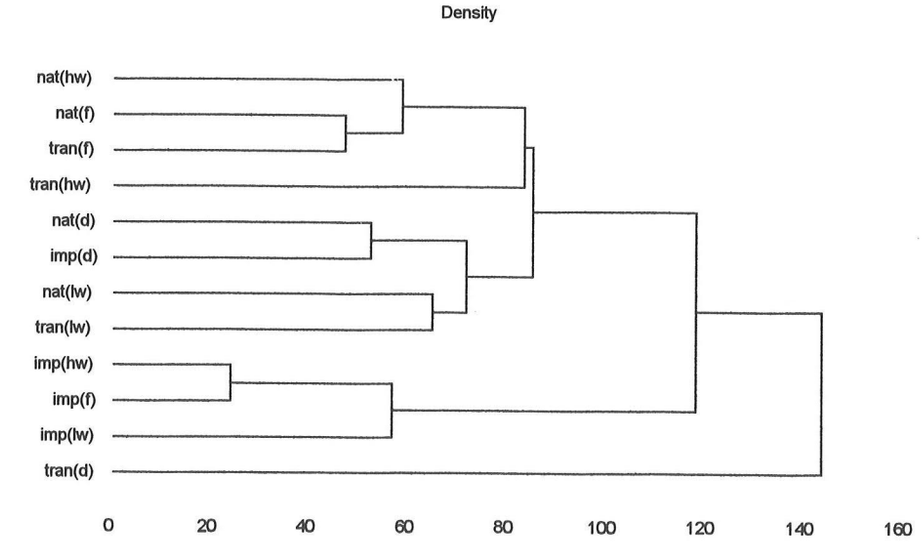
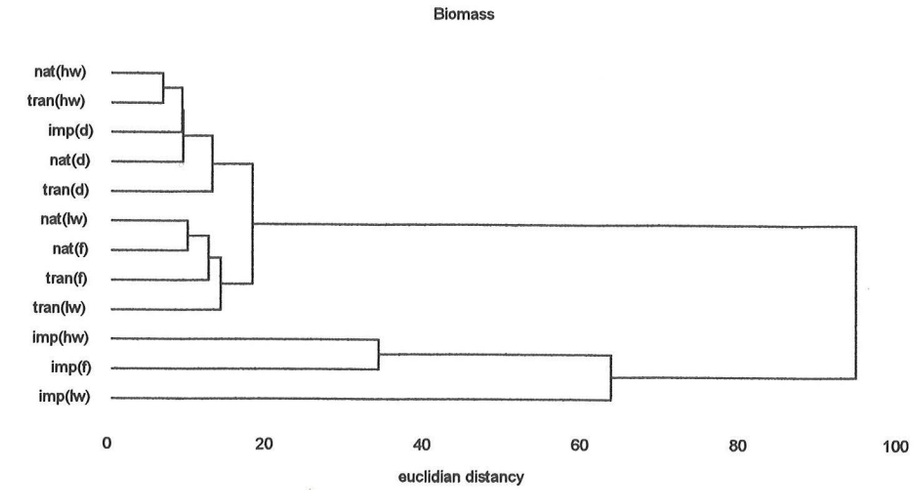


Fig. 5:
Relative contribution of the main taxonomic groups of the community of benthic macroinvertebrates regarding average biomass in the natural, transition and impacted regions of the lake Batata.



(a)



(b)

Fig. 6:
Cluster analysis, regarding relative density (a) and biomass (b) of the benthic macroinvertebrates in the natural (nat), transition (tran) and impacted (imp) regions, in the periods of high water (hw), drawdown (d), low water (lw) and flood (f), in the lake Batata.